NASA's Microgravity Materials Science Program – A Review of Experimental Investigations

Nemak / CASIS Meeting
5 March 2015

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Historical Reference

NASA was not the first to understand and utilize the benefits of processing materials in a microgravity environment.

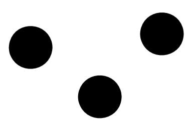
That honor likely goes to William Watts of Bristol, England who in 1753 built a "drop tower" to process molten lead into uniformly spherical shot for firearms

Boughton Shot Tower
Chester, England
1799, 168' tall

Molten lead is poured

Through a sieve

Uniform drops freefall (microgravity), buoyancy effects are minimized

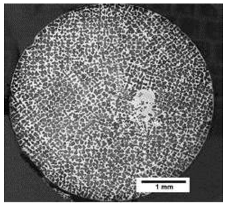


Surface tension dominates forming uniform spheres

Solidified shot lands in a cushion of cooling water

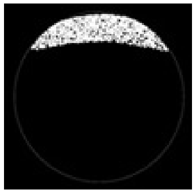
Phoenix Shot Tower
Baltimore, MD, 1828
234' - tallest structure in US
2.5 million pounds shot/year

Microgravity and Physical Phenomena



Gravity drives thermal and solutal convection

- Detrimentally impacts solidification microstructures
- Compromises diffusion studies

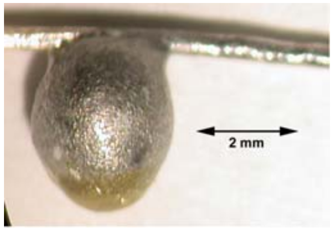


Gravity responsible for sedimentation/buoyancy

- Promotes non-uniform particle distributions

Gravity necessitates, usually, a container to process/study liquids

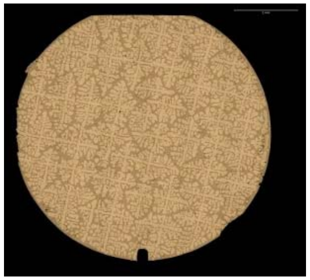
- Compromises accurate study of material properties such as viscosity
- Compromises nucleation/undercooling studies



Gravity overwhelms subtle physical features

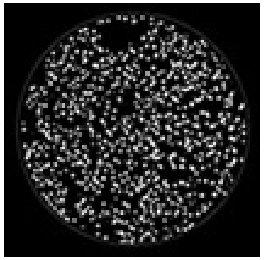
- Thermocapillary effects, surface tension are masked

Microgravity and Physical Phenomena



Microgravity minimizes thermal and solutal convection

- Promotes diffusion controlled growth and uniform solidification microstructures

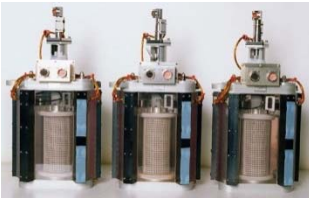


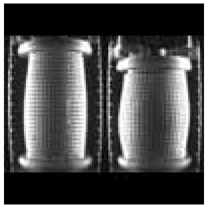
Microgravity minimizes sedimentation / buoyancy

- Promotes uniform particle distributions
  → Advances our understanding of coarsening and sintering

Microgravity minimizes pressure heads

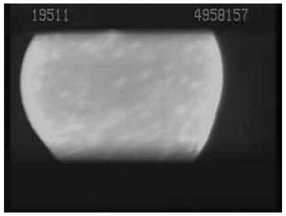
- Reduces defects in semiconductor materials
- Allows study of granular materials





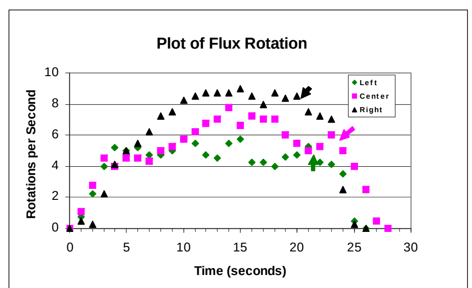
Microgravity eliminates a container to process / study liquids

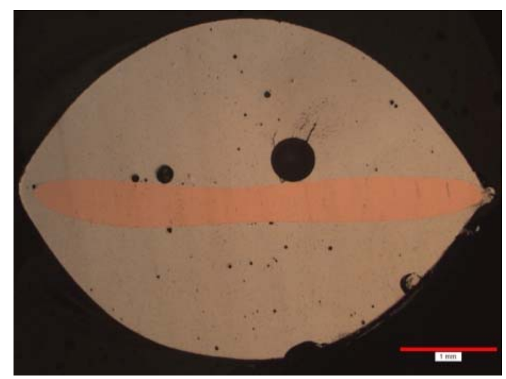
- Improves accuracy of material properties measurements such as viscosity and surface tension
- Facilitates nucleation studies



Microgravity allows observation of subtle physical phenomena

- **Thermocapillary effects, surface tension are now dominant**



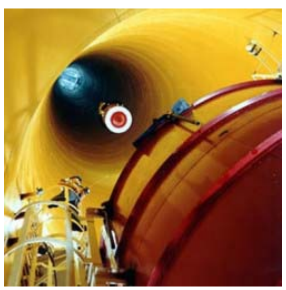


Solder Sample Cross-Section

	Large Bubble (0.53mm)	Small Bubble (0.36mm)
Measured Velocity	5.6 mm/s	4.1 mm/s
Calculated Velocity	5.6 mm/s	4.4 mm/s

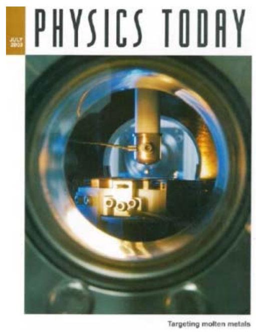
Microgravity "Platforms"

Drop Towers

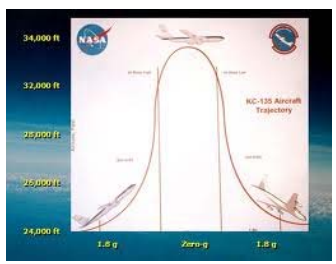


Glenn Research Center
432'
~5.2s μ*g*

Levitators

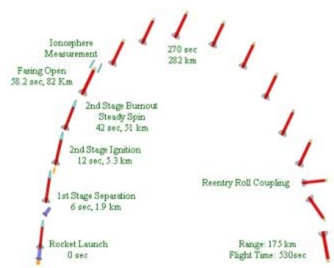


Parabolic Aircraft



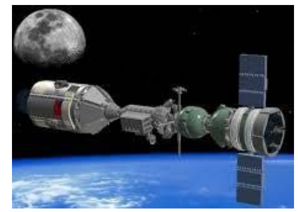
~30s μ*g*

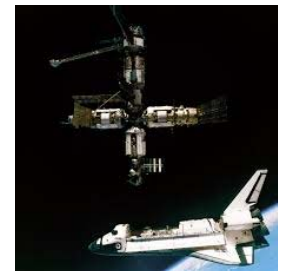
Sounding Rockets

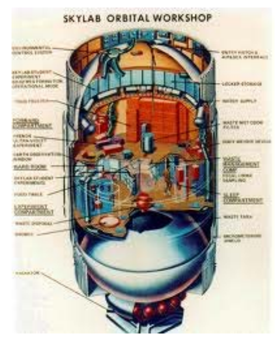


15-25 min μ*g*

Space Vehicles / Stations







Long duration μ*g*

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Long Duration Microgravity Physical Sciences Research	
Foundational Era **1950's to 1980**	**Shuttle Era** **1980 to 2000**
Mercury / Gemini / Apollo / Soyuz Spacecraft / Skylab	**STS and MIR**

Soyuz 6 1969 1st Welding Experiment
Apollo 14 1971 Composite Casting
Skylab 1973-1979

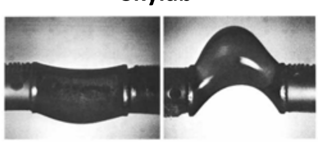
Apollo Furnace

Skylab Materials Processing Facility
Multipurpose Furnace System

TECHNOLOGY

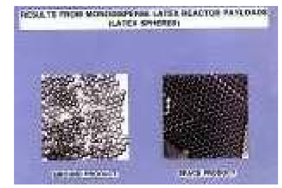
D008 RADIATION IN SPACECRAFT
D024 THERMAL CONTROL COATINGS
M415 THERMAL CONTROL COATINGS
M479 ZERO-g FLAMMABILITY
M512 MATERIALS PROCESSING FACILITY
M551 METALS MELTING
M552 EXOTHERMIC BRAZING
M553 SPHERE FORMING
M555 GALLIUM ARSENIDE CRYSTAL GROWTH
M516 CREW ACTIVITIES / MAINTENANCE STUDY
M518 MULTIPURPOSE FURNACE SYSTEM
M556 VAPOR GROWTH OF II-VI COMPOUNDS
M557 IMMISCIBLE ALLOY COMPOSITIONS
M558 RADIOACTIVE TRACER DIFFUSION
M559 MICROSEGREGATION IN GERMANIUM
M560 GROWTH OF SPHERICAL CRYSTALS
M561 WHISKER-REINFORCED COMPOSITES
M562 INDIUM ANTIMONIDE CRYSTALS
M563 MIXED III V CRYSTALS GROWTH
M564 METAL AND HALIDE EUTECTICS
M565 SILVER GRIDS MELTED IN SPACE
M566 COPPER-ALUMINUM EUTECTICS
T003 IN-FLIGHT AEROSOL ANALYSIS
T025 CORONAGRAPH CONTAMINATION MEASUREMENT
T027 ATM CONTAMINATION MEASUREMENT
T053 EARTH LASER BEACON

Skylab



Skylab: "such tests proved that the processing of metals without using containers is feasible in space".

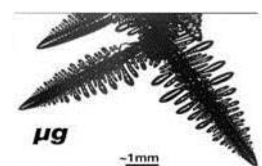
STS3 1982 Latex Spheres
STS9 1983 Spacelab 1
STS17 1985 Spacelab 3
STS51B 1985 Spacelab 2
STS61A 1985 Spacelab D1
STS40 1991 Spacelab LS1
STS42 1992 IML1
STS50 1992 USML
STS46 1992 EUREKA
STS47 1992 Spacelab-J
STS55 1993 Spacelab D2
STS57 1993 LEMZ
STS60 1994 CLPS
STS62 1994 USMP2
STS65 1994 IML2
STS73 1995 USML2
STS76 1996 QUELD LPS
STS77 1996 CFZF SEF
STS78 1996 LM2
STS94 1997 MSL
STS87 1997 USMP4



STS3
Latex
Spheres

STS9
InP
THM

IML1
HgI
VCG



USMP2
IDGE

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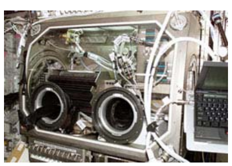
Long Duration Microgravity Physical Sciences Research	
ISS Era 2000 to 2024	Exploration Era 2024 to -
STS and ISS	Moon / Mars / Others

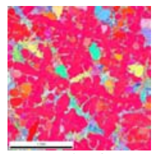

MSRR

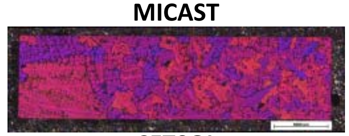

MSG


MWA

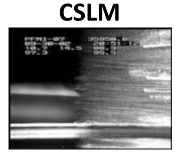
STS107 2003 Columbia

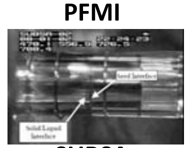
ISS Assembly
- Destiny Lab – MSRR
  - MICAST
  - ICDGSC
  - GTCS
  - DSI
  - SETA
  - METCOMP
  - CETSOL
  - SiSSI
  - GEDS
  - FOGS
  - FAMIS
- *μg* Science Glovebox
  - CSLM
  - PFMI
  - SUBSA
- Maintenance Workbench
  - ISSI
- Columbus Laboratory – ESL
  - THERMOLAB
  - QUASI
  - PARSEC
- Russian Lab
- Japanese Module JEM

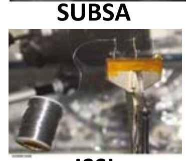

MICAST


CETSOL


CSLM


PFMI


SUBSA


ISSI

In-Situ Resource Utilization

In Space Fabrication and Repair

Summary

Microgravity materials processing arguably began in 1753

First long duration μ*g* experiments were Apollo, Soyuz, MIR, Skylab

- Much Russian welding work
- Wide range of Skylab materials experiments

Spirited period of μ*g* materials science was during the Shuttle age

- Many dedicated flights
- Generally good documentation of results
- Advances made in our scientific understanding
  - → Metals processing, semiconductors, crystal growth, dendritic growth, nucleation

Hiatus due to Columbia tragedy, ISS construction

Microgravity materials science now being conducted on the ISS

- Generally good results, still a <u>long</u> line of experiments

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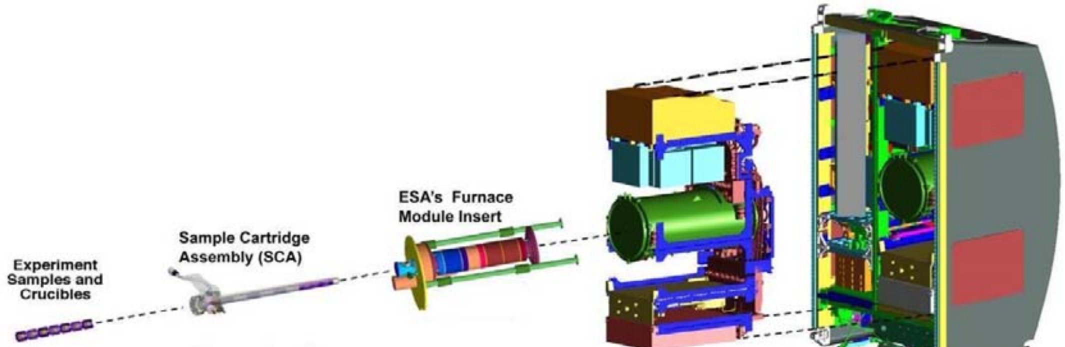
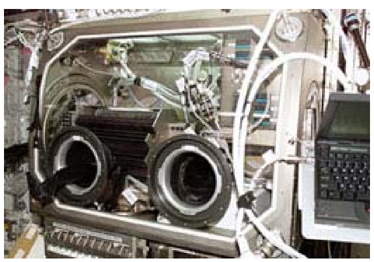
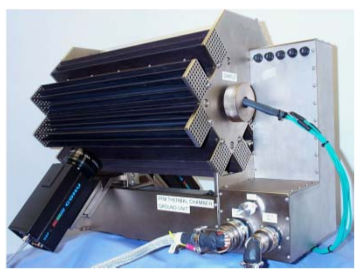
Metals and Alloys: Facilities for Microgravity Research aboard the ISS



Exploded view of the Microgravity Materials Science Research Rack (MSRR) showing ESA's Furnace Module Insert and Sample Cartridge Assembly, Two Furnace Inserts (LGF and SQF) at right.

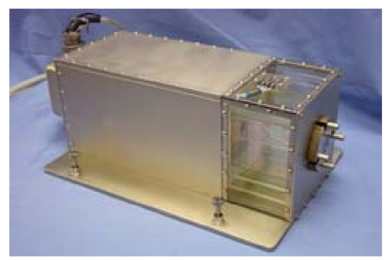


Microgravity Science Glovebox



Pore Formation and Mobility (PFMI) Apparatus

and



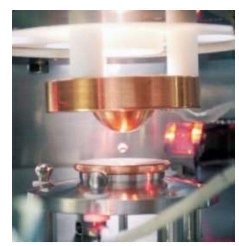
Solidification Using a Baffle (SUBSA) Apparatus

ESA Electromagnetic Levitator

Maintenance Workbench Area

DECLIC: Facility for solidification of transparent materials

Coarsening in Solid/Liquid Mixtures (CSLM) Apparatus



JAXA Electrostatic Levitation Furnace

DLR MAPHEUS short time diffusion module